Effect of Potato Composition on Drum Dryer Capacity

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A model for predicting the production capacity of a single drum dryer for potato flakes was developed. The model uses process parameters for drum speed, steam pressure and number of spreader rolls. It also includes the texture of the raw potato, degree of cooking, starch content of the raw potato and the bulk density of the dried raw potato. The model accounted for variation observed due to cultivar and production year.

Introduction

As a prototype for the development of the methodology for systems study of food processing, we have modelled the potato flake process. The research has resulted in a computer simulator program (1) consisting of an executive program plus predictive mathematical models in subroutines for hot water blanching or precooking (2,3), cooking (4), and for single drum drying potato flakes (5).

The precooker model calculates the leaching of water soluble material from the potatoes by the hot water. From this subroutine the program determines the component mass balances over the unit operation. The cooking model determines the degree of cooking of potatoes brought about by precooking and steam cooking. The drum dryer model calculates the moisture profile of the flakes (and mash) on the surface of the drum.

In addition to these theoretically based models, we developed models for the other unit operations in the potato flake process. These other unit operations are quite simple and straightforward, requiring no extensive model development. The models give sufficiently accurate results for simulation.

The purpose of the simulation is to permit the prediction of mass, energy, and component balances for each unit operation in the process and over the entire process. Preferably, this should be possible based on only a few simple measurements of the raw material (fresh potatoes) plus process parameters such as sizes, temperatures, flow rates, and dwell times.

Unfortunately, to evaluate the drum dryer model knowledge of the capacity or feed rate as a boundary condition was required. The initial model used an empirical equation to calculate this rate. This equation was accurate for the specific lot of Maine Russet Burbank potatoes and for one lot of Long Island Superior potatoes. However, it was not sufficiently accurate to predict subsequent lots. Therefore, the simulator program was not general when drum drying was included. This study was made to resolve that deficiency.

Nomenclature

a, b, c	– coefficients
$C1 \ldots C_n$	– coefficients in the rate equations
$COOK$	– F/FO
C_p	– mash heat capacity (energy/mass temp)
$dP/d\theta$	– mash flow rate (kg/h)
$-d^2P/d\theta^2$	– drum drying rate (kg/h potato mash)
F	– texture as determined on the FTC instrument (force)
FO	– texture of the raw potato dice as determined on the FTC instrument (force)
$HARWK$	– storage time (weeks)
h_c^0	– heat transfer coefficient (energy mass mash/ time length^2 temp mass water)
L	– drum width (length)
M	– moisture (mass water/mass mash)
P	– total quantity of potatoes fed (mass)
$PREC$	– precooker temperature
R	– drum radius (length)
$STCH$	– concentration of starch (mass starch/mass dry potato solids)
T	– mash temperature
T_a	– dry bulb temperature of the surrounding air
T_F	– equilibrium mash temperature
T_S	– saturated steam temperature
$X1, X2$	– independent variables
XA	– steam pressure (Pa gage)
XB	– number rolls
Y	– dependent variable
ω	– drum speed (rpm)
θ	– time
λ	– latent heat of vaporization (energy/mass)

Experimental

Four potato cultivars were used in the study: Russet Burbank from Maine (21–22% solids), Katahdin from Maine (23% solids), Shepody from Maine (19% solids), and Atlantic potatoes from Florida, North Carolina, and Virginia (21–22% solids). The Russet Burbank, Katahdin, and Shepody potatoes were stored either at 3–5°C or room temperature. The Atlantics were usually freshly harvested and stored at room temperature for 3 days before processing. Several small lots of Atlantics were stored at 5–15°C.

Potatoes were peeled in a pilot model (DSA 45) Kunz 45 L steam peeler at a nominal rate of 200 kg/h. The steam pressure was 1400 kPa for 18 s. A rod/reel washer with a series of high pressure (1000 kPa) water sprays removed the loosened peels. Peeling losses were usually less than 10%. No hand trimming was performed. An Urschel slicer (model G-A) cut the potatoes into nominal 1 cm cubes. The free starch released during

delbrückii s.sp. *lactis* produzierten hingegen sehr viel Acetaldehyd (bis 1 mmol/l), kein Aceton, zeigten allerdings auch keinen Konsum von Aceton aus dem Medium an.
Die *L. fermentum*-Stämme fielen ausserdem durch Produktion verschiedener Essigsäureester (*ca.* 3 μmol/l) und 2-Butanon (*ca.* 1.5 μmol/l) auf. Diese Nebenprodukte konnten in Überständen *L. delbrückii* s.sp. *lactis* nicht nachgewiesen werden.
Zwischen dem Gehalt an 'Gesamt'-Carbonylkomponenten und der Geschmacksnote konnte kein signifikanter Zusammenhang nachgewiesen werden. Es besteht höchstens eine schwache Tendenz dazu, dass tiefe Gehalte an 'Gesamt'-Carbonylkomponenten eine Beeinträchtigung des Geschmackes im Greyerzerkäse nach sich ziehen.

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slicing was removed by washing the cubes on a Robins Vibro-Flo shaker/washer.

The potatoes were precooked in a Rietz water blancher (model TL-36K2210) for 18 min and then cooled for 8 min in an Abbott screw conveyor at a water temperature of 22–25°C. The temperature of the precooker was changed in the range 78–87°C to affect different degrees of cooking to the potatoes. The potato cubes were cooked in a continuous atmospheric steam blancher (Robins model No. 20283). Dwell times in the cooker were changed for each experiment to present potatoes cooked to different extents to the drum dryer.

The cooked potatoes were forced through a continuous ricer (6) and further mashed in a Hobart mixer (model 6-800) with the flat beater at the slowest speed for 3 min. No additives were added to the mash.

The mashed potatoes were dried on a cast iron, clean, smooth single drum dryer (Overton Machine Company) with a drum 0.61 m diameter by 0.91 m long. Mash feed rate to the dryer was calculated from the flake rate collected at the doctor blade. All experiments were made with four spreader rolls at a nominal clearance of 0.6 cm.

Carrots were peeled in the high pressure steam peeler using a 5 s steam time at about 1400 kPa. The carrots went through a rod/reel washer, inspection and trimming. The whole carrots were blanched in 82°C water for 18 min and cut into 1 cm pieces with an Urschel cutter. The cut carrots were cooked for 19 min in a steam cooker and puréed in a Fitz mill model D using a 2AA screen with blades.

Potato starch was blended into the carrot purée in the Hobart mixer capable of handling 45 kg of purée. The single drum dryer operated at 531 kPa and 3.5 rpm (14 s drying time).

The texture of the raw, sliced potatoes and of the potatoes leaving the cooker were measured in the Food Texture Corp. testing machine, model TP2, with a back extrusion test cell (4). The potatoes were sampled and immersed in a water bath at 27°C for 3 min. At least six replicate texture measurements were made on the potatoes.

Moisture content was measured by the vacuum oven method, AOAC method 7.003 (7). Starch analyses were made on freeze dried potato powder. The powder was suspended in 50 ml of 0.1 M acetate buffer, pH 4.5, and autoclaved for 1 h at 120°C and 103 kPa. After cooling to room temperature, 1 ml of glucoamylase solution (25 units/ml in 0.1 M acetate buffer) was added and the volume adjusted to 100 ml with the same buffer. The solution was incubated at room temperature for 1 h and 100 μl aliquots were withdrawn and assayed for glucose. Glucose, liberated by the enzyme, was determined colorimetrically by glucose oxidase. Total starch was calculated by multiplying the glucose values by 0.9. Bulk density was determined as follows. The lyophilized raw potato was ground to a powder in a Wiley Mill equipped with a No. 20 screen. The dried powder (approx. 20 g) was mixed in a 50 ml graduate cylinder by rotating the cylinder 10 times. Powder was allowed to settle by standard tamping for 1 min. The volume of powder in the cylinder was determined and bulk density calculated as g/ml.

Results and Discussion

The model for drum drying potato flakes (5) is presented in Eqn [1] where the term $-d^2P/d\theta^2$ is the drying rate.

$$-d^2P/d\theta^2 = \frac{h_c^0 ML(T_s - T) - h_c^0 M\left(\dfrac{T_s - T_F}{T_F - T_a}\right)L(T - T_a)}{\dfrac{\lambda + C_p T}{2\pi R\omega}} \qquad \text{Eqn [1]}$$

The drying rate is a function of the difference in heat transferred in by conduction minus the loss to the atmosphere divided by the sensible heat change in the potatoes. Several auxiliary and boundary condition equations are necessary to evaluate Eqn [1]. The initial feed rate to the drum, $dP/d\theta$, is required to evaluate the equation.

The originally developed empirical equation for calculating the initial feed rate or capacity ($dP/d\theta$) of the drum dryer (5), was batch specific Eqn [2],

$$\text{Rate} = C1 + C2(\omega) + C3(XA) + C4(XB) \qquad \text{Eqn [2]}$$

At least one of the four constants differs from batch to batch. We assumed that the coefficients *C2*, *C3*, and *C4* are not subject to variation of batch because they are parameters of the drum dryer. Evidently the potatoes change and this change must be reflected by the intercept, *C1*. The objective then is to determine the equation which will give the proper intercept.

Potatoes vary in composition and structure due to growing conditions and practices, storage, and processing. Potatoes are about 20% solids, consisting mainly of starch plus much smaller amounts of sugars, proteins, minerals, lipids, pectin, etc. Cultural practices will affect the composition and the structure. During storage the solids and structure change, as reflected in a softening of the potato tissue. In addition, it is common knowledge that in storage starches convert to sugars at cold temperatures and the reverse is true at warm temperatures.

During processing precooking gelatinizes the starch and cooling retrogrades it. Steam cooking further softens the tissue eventually weakening cell integrity. Which of these factors, composition and structure, affect the capacity of the drum dryer? **Table 1** lists the variables we considered as possible controlling factors on the drum capacity.

Is there a structure related variable which could categorize the different lots of each cultivar, e.g. cell size, texture? We tried texture of the raw potato, *F0*, (4) because it would be much easier than cell size to measure routinely and reproduce in a process plant.

Table 2 lists the results of a 2^3 experimental design to determine the significance of cultivar and texture. We included operators as a variable to prove that they would not affect the results. Using the third order interaction as the error estimate,

Table 1 Variables potentially affecting drum drying capacity

Equipment operators
Raw potato texture
Cultivar
Moisture (specific gravity)
Storage time
Storage temperature
Degree of cooking
Texture after cooking
Precooking temperature
Precooking time
Cooking time
Sugars
Pectin
Starch

Table 2 Experimental design and results

	Design		Results		
	+	−		Effect (kg/h)	Significance
A, operator	I	II	A	5.4	NS
B, cultivar	RB	Kat	B	35.4	$p < 0.05$
C, texture, mash (kg)	165	112	C	9.1	NS
			AB	−0.5	NS
			AC	−6.8	NS
			BC	−15.9	$p < 0.05$

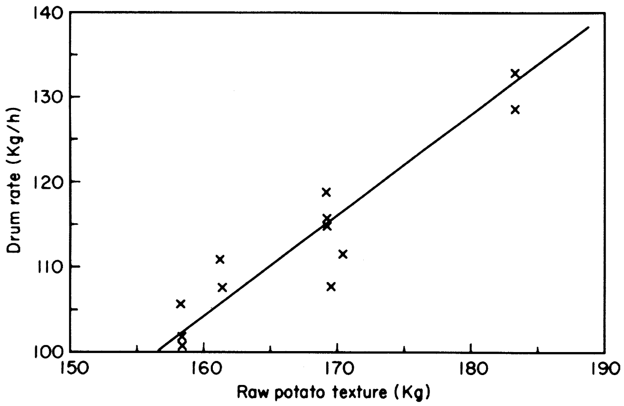

Fig. 1 Plot of drum dryer rate (kg/h) vs texture (kg) of the raw potato (Maine Katahdin)

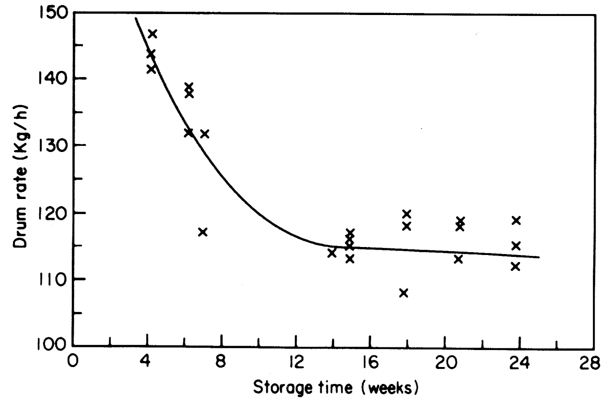

Fig. 3 Plot of drum dryer rate (kg/h) vs degree of cooking for Maine Russet Burbank Potatoes. ○, storage of 8 weeks or less; ×, storage greater than 8 weeks

cultivar, and the cultivar/texture interaction were significant at the 0.05 level.

Some of the variables are confounded making it extremely difficult to elucidate which actually affect the rate. Specific gravity or solids content was investigated. There was no apparent correlation between dry matter content of the cooked potatoes and rate. Different cultivars which, in the two specific lots investigated, had almost identical moisture levels, gave completely different feed rates. This indicated that cultivar and not moisture was a controlling variable. (However, it is generally accepted that specific gravity does affect drum rate and performance.)

To determine the variables inherent to the potato which control the drum capacity, we plotted the rate versus the individual variables to look for trends. Keep in mind that the variables are confounded so the plots should not be interpreted too closely. Once a correlation was suspected, that variable was included in a linear model, determined using the SAS computer software (8). The linear model was of the form:

$$Y = a + b\,X1 + c\,X2 + \cdots \qquad \text{Eqn [3]}$$

where Y is the rate and $X1$, $X2$, etc. are the independent variables. **Figure 1** is a plot of rate vs texture of the raw potato *(F0)* for Katahdin potatoes. There is a trend (remember the data are confounded), the drum rate increases with texture of the raw potato.

Figure 2 is a plot of rate vs storage time in weeks (*HARWK*). Again there is a trend but no strong correlation. The rate dropped with storage.

We suspected that starch content and the effect on starch due

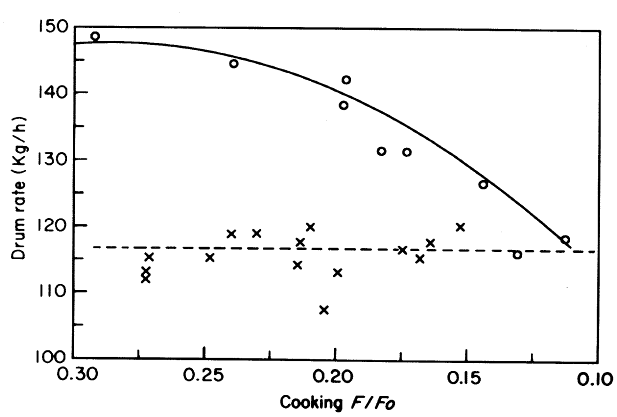

Fig. 2 Plot of drum dryer rate (kg/h) vs time in storage (weeks) for Maine Russet Burbank Potatoes

to cooking were important variables. **Figure 3** plots rate vs cooking (*F/F0*). Cooking did effect the rate; but only for freshly harvested potatoes (less than 8 weeks in storage). At less than 8 weeks from harvest, cooking decreases the rate. After this time it has little effect.

Using SAS we tried fitting the data to a linear model as listed above. All experimental work was done at 3.5 rpm, 531 kPa, and with four spreader rolls. Because this aspect of the model would not change, these terms were included in the intercept calculated in each SAS model. The model used three variables; raw potato texture (*F0*), cooking (*F/F0*), and storage time in weeks (*HARWK*). We obtained a correlation as listed below

$$\text{Rate} = 27.7 + 0.3(F0) + 68.8(COOK) - 0.68(HARWK) \qquad \text{Eqn [4]}$$

with an R^2 of 0.73 for 43 data points.

We plotted the rate vs the precooker temperature but found nothing of note. We do know precooking temperature affects cooking from results of the cooking model (4). Therefore, the next model included four variables—the previous three plus precooker temperature (*PREC*). The correlation improved slightly, to an R^2 of 0.74 for 43 data points for the equation as listed below

$$\text{Rate} = 38.5 + 0.35(F0) + 67(COOK) - 0.64(HARWK) - 0.024(PREC) \qquad \text{Eqn [5]}$$

The major dry component of the potato is starch. To determine if this had any effect on the rate we tried spiking 45 kg samples of mashed potatoes with potato starch. The starch visibly changed the performance of the drum. The potato mash appeared to be more sticky and to stick better to the drum. However, the results were inconclusive.

We tried adding starch to a reasonable facsimile of a starchless potato. We tried using carrots because they contain almost no starch.

To purées of cooked carrots we added starch at levels from 0.4% to 11.2%. With no added starch the carrots did not stick to the drum. Drum drying failed. When the starch was added the purée became sticky. At low concentrations of starch the mash readily stuck to the drum and processed satisfactorily. At higher concentrations the mash became so sticky that it 'stuck to itself' and the drying rate dropped off. In all cases in which starch was added the carrots dried to a good product. The dried carrot flakes rehydrate quickly, cold or hot, practically on contact. Apparently starch influences drum rate. We included starch concentration of potatoes *(STCH)* in the next model plus the previous four variables. The R^2 for the model improved to 0.86. The correlation equation was

$$\text{Rate} = 242 + 0.3(F0) + 52.6(COOK) - 1.7(HARWK) - 1.9(PREC) - 29.2(STCH) \qquad \text{Eqn [6]}$$

Another important component of potatoes is sugar. We tried spiking potatoes with sugars as before but there was no difference. In a way this is not surprising. We have drum dried potato cultivars used for making potato chips. These potatoes contain very low levels of sugar. In fact, one cultivar, Atlantic, contained essentially no measurable sugars. Yet they processed quite well.

Can we simplify Eqn [6]? The intercept, C_0 includes the contribution from the drum process parameters—drum speed, steam pressure, and number of spreader rolls. Because all this work was done at one set of conditions we made those the base conditions for the correlation. These terms will be added into the model. The second term, (*F0*), can not be predicted at this time so it must remain as is and be measured for each lot of potatoes.

The third term, (*COOK*), should be predictable from the cooking model. The cooking model includes the temperature of the precooker, *PREC*. Therefore, if we include the cooking model to predict cooking, the (*PREC*) term should be superfluous.

What changes during storage are reflected in the term (*HARWK*). There are two obvious changes. The texture changes as the potatoes get soft and the starch and sugars convert depending on the temperature. These should be accounted for in the (*F0*) and (*STCH*) terms.

Therefore, using 3.5 rpm, 531 kPa, and four spreader rolls as the base condition, Eqn [6] was rewritten as Eqn [7]:

$$\text{Rate} = C_0 + C_1(F0) + C_2(COOK) + C_3(STCH) + C_4(\omega\text{-}3.5) + C_5(PRESS\text{-}531) + C_6(ROLLS\text{-}4) \qquad \text{Eqn [7]}$$

Using a Hooke-Jeeves pattern search we determined the best values for the coefficients. The correlation coefficient was 0.910 ($R^2 = 0.8284$) but the value of C_0 was only -7.5. With such a small intercept we were able to redo the correlation, forcing it through the point $C_0 = 0.0$. The resulting equation was:

$$\text{Rate} = C_1(F0) + C_2(COOK) + C_3(STCH) + C_4(\omega\text{-}3.5) + C_5(PRESS\text{-}531) + C_6(ROLLS\text{-}4) \qquad \text{Eqn [8]}$$

where

$$C_1 = 0.41;\quad C_2 = 36.3;\quad C_3 = 57.2;\quad C_4 = 13.6;\quad C_5 = 0.03;\quad \text{and}\quad C_6 = 19.5.$$

The value for the correlation coefficient was still 0.910 ($R^2 = 0.8284$). The calculated rates are plotted versus the experimental values in **Fig. 4.** The average error (|Calc − Exp|/Exp) was only 3.5%.

Because the starch content of the mash would be impractical to use on a commercial process, we substituted the starch content

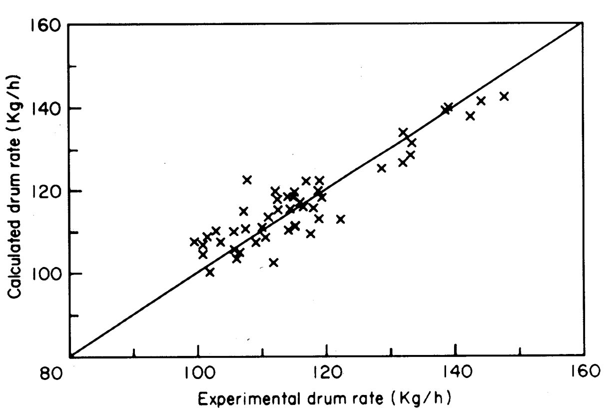

Fig. 4 Plot of calculated drum dryer rate (kg/h) vs experimentally determined drum dryer rate (kg/h) for 1 year of processing

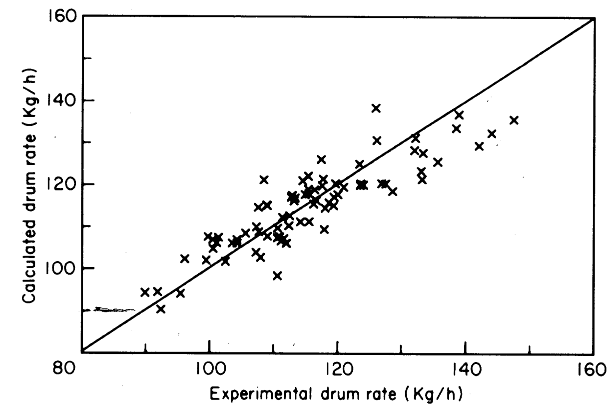

Fig. 5 Plot of calculated drum dryer rate (kg/h) vs experimentally determined drum dryer rate (kg/h) for 2 years of processing

of the raw potato in Eqn [8] and correlated the data using the pattern search program. The coefficients determined were:

$$C_1 = 0.54;\quad C_2 = 56.0;\quad C_3 = 20.0;\quad C_4 = 13.6;\quad C_5 = 0.03;\quad \text{and}\quad C_6 = 19.5.$$

The correlation coefficient was 0.896 ($R^2 = 0.8028$).

The previous correlation was developed using Russet Burbank and Katahdin potatoes harvested in the autumn of 1987 and Atlantic potatoes harvested in the summer of 1988. When we tried to apply the model to Russet Burbank and Shepody potatoes harvested in the autumn of 1988 it failed. The experimentally measured rates were 10–20% lower. Apparently, there is yet another compositional factor of the potatoes which varies with the growing year.

It is common knowledge that specific gravity of the raw potatoes affects drum performance. However, we found no significant difference in the specific gravities or solids, which are usually determined from the specific gravity. Specific gravity is not sensitive enough for the model; but, we tried using the bulk density of lyophilized powder from the raw peeled potato (see Experimental). We added a term for bulk density to the model of Eqn [8], included data collected for Russet Burbank and Shepody potatoes harvested in the autumn of 1988, and varied the drum speed and steam pressure. Performing a Hooke-Jeeves pattern search to determine the best values for the coefficients, we obtained Eqn [9] for 80 data points.

$$\text{Rate} = C_0 + C_1(F0) + C_2(COOK) + C_3(STCH) + C_4(DENSITY) + C_5(\omega\text{-}3.5) + C_6(PRESS\text{-}531) + C_7(ROLLS\text{-}4) \qquad \text{Eqn [9]}$$

where

$$C_0 = 13.97;\quad C_1 = 0.38;\quad C_2 = 35.97;\quad C_3 = -12.75;\quad C_4 = 74.25;\quad C_5 = 15.65;\quad C_6 = 0.0474;\quad \text{and}\quad C_7 = 19.50.$$

The value for the correlation coefficient was 0.878 ($R^2 = 0.7715$). The calculated rates are plotted versus the experimental values in **Fig. 5.** The fit is quite good. In fact, the average error (|Calc − Exp|/Exp) was only 4.1% or 4.7 kg/h. Since the data are based on only three processing seasons (2 years), we plan to continue testing the model for several more years.

Summary

We have developed a computer program for simulating or modelling potato flake processing. The last step in the process is the drum dryer. The drum dryer model needs the production capacity of the drum as input to the model. By running the drum dryer under various processing conditions with different feed potatoes processed using different processing conditions we developed a model for predicting the production capacity of a single drum dryer for potato flakes. With this step completed the potato flake process can be simulated giving the potato industry the ability to simulate and optimize processing saving money, energy, utilities, and maximizing nutrition.

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